Model Development and Experimental Validation of Reactive Gas and Pyrolysis Product Interactions with Hot Carbon Chars

Completed Technology Project (2015 - 2018)

Project Introduction

Ablative thermal protection system (TPS) materials are required for the extreme heating encountered during hypersonic entry into the Martian, Venusian, and Outer Planet atmospheres as well as for manned and sample-return missions into the terrestrial atmosphere. This proposal addresses the Topic 1: Advanced Thermal Protection Materials Modeling. Research pertaining to TPSs, specifically the ablative materials used for TPSs, remains one of the main focal points of NASA's technology development, with TPSs mentioned in 7 of 14 space technology roadmaps. The research proposed here is most closely associated with TA09: Entry, Descent and Landing. We propose to provide high-quality experimental data to support the development of high-fidelity, physics-based ablation models that include internal reactions and the chemical evolution of pyrolysis gases within hot carbon chars. Our primary objectives are to: (i) perform experiments with well-controlled test conditions and quantified uncertainties on all relevant test variables; (ii) conduct these experiments in a configuration that can be directly simulated by using coupled Fluid Dynamics (FD) and Material Response (MR) codes, and (iii) use the data in a high fidelity coupled FD/MR framework to extract parameters and validate models. We propose a 3-year research program to accomplish our objectives. We will investigate both internal oxidation reactions in partially dissociated air flows and the chemical evolution of representative pyrolysis gas mixtures by heterogeneous surface reactions with a hot char. Experiments will be performed in a furnace-heated, flow tube configuration, using a porous carbon material as a char simulant. We will regulate input mass flow rates, measure absolute and differential pressures across the porous specimen, and monitor sample temperatures. We will use a microwave discharge and chemical titration techniques to produce and quantify partially dissociated air flows and calibrated gas mixtures representative of incipient phenolic pyrolysis products to study the chemical evolution of pyrolysis gases. Gas compositions will be monitored as a function of temperature, pressure, and flow rate after they exit the hot carbon char simulant using a combination of advanced mass spectroscopic techniques. Changes in char density, permeability, and microstructure due to oxidative attack or carbon deposition by coking reactions will be documented and correlated with gas composition measurements. Scanning electron microscopy analyses of specimens prior to and post furnace heating will be implemented to characterize changes in the microscale morphology and chemical composition of the char upon carbon fibers/ pyrolysis gases interactions. We will use the data obtained through the experiments in a numerical modeling framework designed to simulate detailed coupling problems that involved pure flow and porous media. The framework couples a FD solver with a MR code through detailed mass, momentum and energy balance, which ensures that transport phenomena at the interface are captured. We will use the non-reacting experimental results to validate the coupling scheme and calculate the macroscopic parameters such as permeability, in porous modeling zone. Finally, we will assemble a finite-rate chemistry model using a volume-averaged technique for gas-surface

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Table of Contents

interactions inside the porous chars. We will use the data to select and calibrate the kinetic rates. The benchmark data sets generated by this work are essential for modelers to construct and validate internal reaction and pyrolysis gas evolution models for high-fidelity ablation simulations. The outcome of this research will raise the Technology Readiness Level of the MR codes used for predicting ablation performance in real flight environments. The long term payoff for NASA will be a more sophisticated suite of MR codes with advanced flow field coupling capabilities for ablative TPS sizing.

Anticipated Benefits

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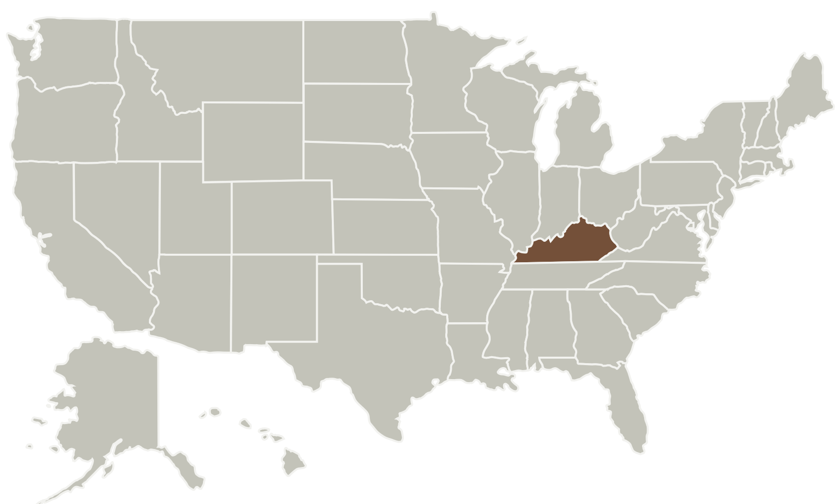
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of Kentucky	Lead Organization	Academia	Lexington, Kentucky

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

University of Kentucky

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

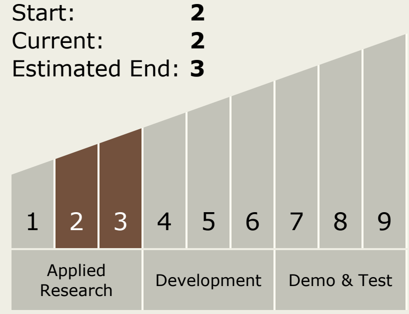
Hung D Nguyen

Principal Investigator:

Alexandre Martin

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Primary U.S. Work Locations

Kentucky

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Areas

Primary:

- TX09 Entry, Descent, and Landing
  - └ TX09.4 Vehicle Systems
    - └ TX09.4.5 Modeling and Simulation for EDL

Target Destination

Foundational Knowledge